



AL-TR-89-022

AD:

Final Report
for the Period
June 1986 to
September 1988

Los Alamos National Laboratory's Antiproton Research

April 1989

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AD-A208 404



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prepared for the

Astronautics Laboratory (AFSC)

Air Force Space Technology Center
Space Systems Division
Air Force Systems Command
Edwards Air Force Base, California 93523-5000

89 6 01 087

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FOREWORD

This final report gives the status of the experiment being performed by Los Alamos National Laboratory to measure the gravitational mass of an antiproton in a vertical drift tube at the completion of partial Astronautics Laboratory (AFSC) funding. The project was jointly funded by the Department of Defense and the Department of Energy. AFAL Project Manager was Capt William Sowell.

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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release, Distribution Unlimited	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE		4. PERFORMING ORGANIZATION REPORT NUMBER(S)	
5. MONITORING ORGANIZATION REPORT NUMBER(S)		6a. NAME OF PERFORMING ORGANIZATION Los Alamos National Laboratory	
7a. NAME OF MONITORING ORGANIZATION U.S. Department of Energy		6b. OFFICE SYMBOL (If applicable) P-15	7b. ADDRESS (City, State, and ZIP Code) P.O. Box 5400 Albuquerque NM 87115
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Astronautics Laboratory		8b. OFFICE SYMBOL (If applicable) LSX	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFSC Forms 277: AFAL 89026, RPL 67025
10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62302F PROJECT NO. 5730 TASK NO. 00 WORK UNIT ACCESSION NO. QL		8c. ADDRESS (City, State, and ZIP Code) Edwards AFB CA 93523-5000	
11. TITLE (Include Security Classification) LANL Antiproton Research			
12. PERSONAL AUTHOR(S) N.S.P. King, Ph.D.			
13a. TYPE OF REPORT Final Report	13b. TIME COVERED FROM Jun 86 TO Sep 88	14. DATE OF REPORT (Year, Month, Day) 14 Apr 89	15. PAGE COUNT 125
16. SUPPLEMENTARY NOTATION AL-TR-89-022 (page count includes appendix 2, maintained at AL)			
17. COSATI CODES FIELD GROUP SUB-GROUP 20 07 20 08		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Antiprotons; Electromagnetic Traps, Penning Traps; Foil Degraders; CERN LEAR, RFQ	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) This is the report on the status of the experiment being performed by Los Alamos National Laboratory (LANL) to measure the gravitational mass of an antiproton in a vertical drift tube, at the completion of partial Air Force funding. LANL must develop the capability to capture, cool, and store millions of antiprotons produced at the target of the large accelerator at CERN, the European nuclear research center. Of interest to the AL are the ion traps needed to do this. (These traps can be used as an intermediate step in the production of antihydrogen because they can, in principle, hold useful quantities of antiprotons at low temperatures. Antihydrogen annihilation is a potential energy source for very high performance space propulsion systems). A number of successful trapping experiments were performed, the details of which are in Appendix 2 of this report and in Holzheiter et.al. "Captured 2-10 KeV Negative Hydrogen Ions Into a Penning Trap", Physica Scripta T22, 290 (1985).			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Gerald D. Nordley, Maj, USAF		22b. TELEPHONE (Include Area Code) (805) 275-5653	22c. OFFICE SYMBOL AL/LSX

FINAL REPORT ON AFAL FUNDING OF LANL
ANTIPROTON RESEARCH

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The following is a status report of the LANL basic research effort on slowing down and trapping antiprotons in preparation for an experiment at the CERN facility in Geneva, Switzerland to measure the gravitational acceleration of antiprotons. Funding for this experiment has and continues to be derived from a variety of sources both internal and external to Los Alamos. An important early contributor to the funding of this effort was obtained from the Air Force Rocket Propulsion Laboratory under Colonel Mason. The primary interest within the Air Force at that time was to help initiate an experimental program to evaluate possibilities for trapping and storing significant quantities of antiprotons as a springboard to permit evaluation of the utility of antiproton technologies for propulsion and high density energy storage for use in future space programs.

Los Alamos received Air Force funding in 1986 in two installments, one near the beginning of the year and the second, on the last day of the LANL fiscal year. The second installment was carried over into and costed in our FY1987. A letter summarizing utilization of these funds was sent to Captain Sowell on January 22, 1987. A copy of this letter is included below in Appendix 1. The Air Force funding provided a critical addition to both internal LANL and limited DOE support to permit the formation of a collaboration to begin experimental work on the project of both slowing down and trapping of antiprotons necessary for continued low energy studies.

The current status of the LANL experimental program will be presented with an emphasis on the slowing down and trapping aspects of the project as these are of most interest to the Air Force. For completeness a brief overview of the experiment will be given as well.

Experiment PS200 (Ref. 1&2) is to be carried out at the Low Energy Antiproton Ring (LEAR) at the CERN facility in Switzerland. The motivation is to measure the acceleration of the antiproton in the earth's gravitational field to provide an

experimental test of quantum gravity field theories and the concept of the weak equivalence principle. The latter is the assumption that the inertial mass embodied in the well known $F=ma$ is the same mass as appears in the force due to gravity in Newtonian gravity given by $F=GmgM/r^2$. Other experiments at LEAR (PS189 ref 3, PS194 ref 4) will attempt to measure the inertial mass of the antiproton in the next few years while PS200 focusses on its gravitational mass.

Quantum gravity field theory predictions result in different forces due to a gravitational field from the earth (normal matter) interacting with a proton vs. an antiproton. The magnitude of this effect depends on the range of the vector and scalar gravitational potential components when compared to usual tensor Newtonian component. A precision field on an antiproton will therefore permit a test of these theories.

An important difference of relevance to Air Force interests between all of the presently proposed experiments is the fact that the inertial mass measurements utilize, in one case, only single trapped antiprotons or in the other, make no attempt at storage at all. The gravity experiment as it is presently conceived will utilize cooled, trapped antiprotons in large numbers to obtain a statistically significant result. All of the experiments require a serious effort to obtain a source of low energy antiprotons well below the 105 MeV/c (5.9 MeV) currently available from LEAR. The LEAR facility at CERN is currently the only viable source of antiprotons at MeV energies available for experiments.

The PS200/LANL approach to slowing down and trapping antiprotons has been divided into a number of projects being investigated independently with the intention of combining several concepts in a series of tests at the LANL Ion Beam Facility (IBF) within the next year. This will permit tests which will not differ much from those expected with antiprotons.

Methods for slowing down antiprotons to less than 100 KeV currently being pursued are:

- 1) an RFQ decelerator directly injected from LEAR.
- 2) an "anti-cyclotron" or a small cyclotron in which antiprotons are injected at the periphery of a magnetic field and through different techniques loose energy causing them to spiral inwards to a central extraction region.
- 3) a degrading foil designed and strategically placed near a trapping volume such that the energy and angular distribution of degraded low energy antiprotons is optimized for capture.

LANL is a world leader in designing and constructing compact, low energy RFQ accelerators. A number of designs have been completed specifically tailored to matching LEAR output conditions to permit obtaining a 50 KeV antiproton beam for injection into a multiring trap (Ref. 5). The RFQ concept has been pursued to the present level to provide a known solution to the technical problem of deceleration of antiprotons. This was also the concept discussed in the original PS200 proposal for the same reason. We are currently pursuing alternatives due to the lack of sufficient funds to implement an RFQ. Current estimates are \$2.5M to build and install and RFQ at LEAR. A particularly nice feature of the RFQ is the ability to have a set of internal vane structures which could be changed relatively easily to provide different output energies for a community of low energy antiproton users. At present no further work is underway on the RFQ concept.

The "anticyclotron" trap injector concept is being tested by modifying an existing superconducting cyclotron trap initially constructed for experiments in x-ray emission resulting from bound antiproton-proton cascades (antiprotonic hydrogen level transitions). In this case low pressure gas and strategically placed degrading foils caused the injected antiprotons from LEAR to spiral inward until they were captured by protons. The present modeling studies are to permit installing an electrostatic ejection system in the central region of the magnet system. Ejection conditions would be a short pulse (< 100 ns) of approximately 10 to 15 KeV antiprotons. Injection losses from LEAR are expected to be 75%.

Low energy axial injection from external ion sources have been utilized successfully on a number of cyclotrons and the idea of ejecting rather than injecting should work. Some problem areas include a vacuum isolation foil between the ejection channel and the cyclotron trap and transport of 10 KeV antiprotons through the magnetic field transition region into the external trap system. Experiments to explore this approach are being planned at LEAR in the fall of 1989 (Ref. 6). Collaborators from CERN and PSI (formerly SIN in Switzerland) are taking a lead role in this area.

The use of degrading foils for reducing the energy of antiprotons available to experiments at LEAR has been considered as an option for a number of years. Calculations to estimate the overall efficiency of this approach are difficult for the lowest energies since one ranges out the antiprotons in a foil and then obtains the number transmitted as a function of foil thickness by in essence calculating straggling widths. These widths depend on effective charge as well as the stopping power at KeV energies where little data exists and parameterizations are frequently used. Low energy angular distributions are also at energies far from the regime where

simple approximations such as are used in Moliere scattering can be used. Modeling efforts utilizing Monte Carlo codes such as TRIM and calculations with the Janni range-energy computer code have permitted investigating straggling widths and effective charge sensitivities for antiprotons vs. protons. Ultimately however it is necessary to obtain data for antiproton degrading to low energies for good estimates relevant to PS200.

An experiment utilizing Be foils and 21 MeV antiprotons was carried out by the University of Washington at LEAR a few years ago (Ref. 7). They obtained a limited data set since only 36 hours of beam time was available. Indications were that antiprotons were not greatly different from protons in their stopping powers and ranges. A more recent experiment carried out by PS200 personnel (Ref. 8) involved 105.5 MeV/c antiprotons and protons degraded by thin CH foils. The apparatus was designed and preliminary experiments performed at the LANL Ion Beam Facility (IBF) prior to shipment to LEAR. The range of antiprotons was approximately 2.5% ($10 \mu\text{m}$) longer than for protons as determined by the 50% transmission degrader thickness. The 10% to 90% transmission points corresponded to a variation in degrader thickness of approximately $25 \mu\text{g/cm}^2$. This means optimization of a degrading foil for obtaining low energy antiprotons for a given incident energy near 5 to 6 MeV will require thickness variations on the order of a few microns. Variations by tens of KeV in the incident LEAR antiproton energy will therefore require compensating the degrading foil thickness by a few microns. Designs to do this are being considered in the PS200 degrading-trapping apparatus.

A number of trapping experiments have been successfully carried out over the past few years. These required interfacing an existing few KeV to 100 KeV ion source with a low energy beam transport system to a vertical, superconducting magnet with a room temperature bore. A small Penning type trap was designed, built, and installed in the central field region of this magnet along with high voltage connections to permit switching the entrance and exit caps for electrostatic capture and release of charged particles. A microchannel plate (MCP) detector was used to detect ejected trapped particles. Some of the first experiments to trap externally injected hydrogen ions have been carried out with this equipment (Ref. 9).

Emphasis in trapping particles is currently being directed to designing and testing more complex "multi-ring" traps and developing techniques for cooling the trapped particles to few KeV energies. Initial experiments in trapping particles and detecting electrical signals from an extended harmonic trap have recently been completed (Appendix 2). Extended multiring traps are necessary due to the temporal pulse widths from LEAR (250 ns) and the injection energy distributions both of which require inner "drift" regions in a

trap to permit injection over extended periods of time before electrostatic closure of the trap entrance. After trap closure it is necessary to reduce the average energy of the trapped particles to permit controlled ejection to other traps and the gravity measurement equipment.

Cooling techniques are currently being investigated at LANL as well as by other collaborators at Texas A&M University and in Italy. The concepts are summarized in the proceedings of a LANL hosted workshop (Appendix 2).

Appendix 1: Letter to Capt. Sowell on LANL antiproton project utilization of Air Force funding

Appendix 2: Cooling Workshop proceedings

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- 7) G. Gabrielse, et al; Phys. Rev. Lett. 57, 2504 (1986)
- 8) N. W. Hill, D. H. Holtkamp, N. S. P. King and G. L. Morgan (to be published)
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Appendix 1

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

DATE 22-January-1987
IN REPLY REFER TO P-15-87-U-19
MAIL STOP MS-D406
TELEPHONE (505)-667-4415

Captain William Sowell
AFRPL/CX
Air Force Rocket Propulsion Laboratory (AFSC)
Edwards Air Force Base, California 93523

Dear Captain Sowell;

The past year at Los Alamos has seen the achievement of a number of milestones. The most significant of these is the formal approval of our experiment at CERN. This formal approval has enabled us to go forward with the prototype development of the experimental equipment. The important milestone we have achieved in this area is the trapping of an external beam of 10 keV H^- ions in a pulsed ion trap. This trap was a prototype of the first stage of our trapping/cooling system for the experiment.

The RPL funding we received came at a critical time, in two separate installments, the last appearing the last day of FY86. The first installment was spent in supporting priority projects in the experiment. About half was used to permit Texas A&M University personnel and shops to construct the pulsed ion trap that was used at Los Alamos to trap a significant number of 10 keV H^- ions and to release them in a controlled manner. Because antiprotons have the same charge and mass we feel a similar success can be anticipated at CERN. The remainder of the first installment was spent on materials essential to keeping other parts of the gravity experiment moving forward. Los Alamos sent a μ VAX work station and money to CERN to keep the LEAR upgrade on schedule. This upgrade, as you know, was to permit high quality, low energy (2 MeV) antiprotons to be delivered to our trapping system in preparation for launching in the gravity experiment.

Captain William Sowell
P-15-87-U-19

- 2 -

22-January-1987

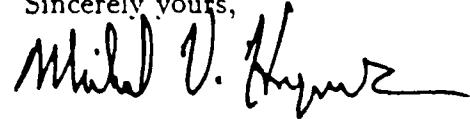
Money arriving on the last day of FY86 has been carried over and almost completely costed to date in FY87 in further developing a half-scale working prototype of our design for the actual CERN catching trap. This device is currently being installed at Los Alamos for preliminary tests. This trap has quite a different design than anything that has been built before. We expect results very soon from our testing program.

In FY87 and FY88 we expected substantial support from the Air Force. For reasons that remain unclear to me this funding will be not forthcoming. Despite this, the effort at Los Alamos will move forward although at a slower pace. Due to the withdrawal of expected support by the Air Force, we plan to delay the construction of the RFQ decelerator. The design will be carried to the point of mechanical drawings in anticipation of a more optimistic funding profile next year. This delay will not derail the planned execution of the experiment in 1990-1991; It will make 1989 a very hectic year for fielding equipment at CERN. In addition to delaying the RFQ construction, we are exploring alternatives to this device.

As you can see, the funding from RPL this past year was crucial to achieving the short term milestones, and to the long range scheduling of our experiment. More importantly, this funding allowed us to leverage matching funds and resources from inside the Laboratory. Thus, any funding that RPL can provide this year or next will essentially double with the leverage it will allow us to apply.

Thank you again for your past support of our efforts. We look forward to working more closely together in the future.

Sincerely yours,



Michael V. Hynes

MVH/mvh
cc: P-15 file
cc: CRM-4
Enc. a/s

Appendix 2

**WORKSHOP ON TRAPPING AND COOLING
IN PS 200**

MAY 24 - 25, 1988

**LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS, NM 87544**

**ORGANIZED BY
M.H. HOLZSCHEITER
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The Astronautics Laboratory copy of this appendix is kept in the Astronautics Laboratory branch of the Air Force Flight Test Center Technical Library. Copies may be obtained from Los Alamos National Laboratory at the above address.